**Calculating the Molar Volume of Hydrogen Gas**

*Read the following, and the attached lab instructions in time for the* ***pre-lab quiz****!*

Up until now, we have been learning some different Gas Laws, such as Boyle’s Law, Charles’ Law, and Gay-Lussac’s Law. We also learned how we can combine these relationships into the Ideal Gas Law (PV = nRT). In this experiment, you will learn how to use this relationship to make inferences about the behaviour of gases.

Your goal for this lab is to determine the molar volume of Hydrogen Gas at STP.

You will figure this out by reacting magnesium ribbon with concentrated hydrochloric acid and then measuring the volume of hydrogen gas produced. Then you will use the ideal gas law to go from the volume you found at your conditions to that of STP conditions.

Mg­(s) + 2HCl(aq) 🡪 MgCl2(aq) + H2(g)

Quite often, even high-level scientific papers will state that they ‘followed the protocol of Scientist et al. with the following changes’. Your lab is no different. The instructions and safety for the lab are located on pages 512-513 of your text (McGraw-Hill Chemistry 11) and are also attached. The following changes will be made:

Safety: You will need gloves and goggles but not an apron.

Step 2. Use a piece of magnesium 3-5cm long. If more gas is produced than can be held in the graduated cylinder, you will have an inaccurate measurement and your results will be invalid.

Step 5. We don’t have enough barometers for the entire class, so the teacher will tell you the room pressure:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_kPa

**If you are having difficulty with the math or the concepts, see chapter 12 in your text.**

Make sure your observation chart is complete.

It will be initialed by your teacher at the end of class.

Answer questions 1, 2, 4-6 about the lab from pages 512-513 and do the following questions.

**Additional Questions**

7. What type of reaction has occurred here? How do we know a chemical reaction has occurred?

8. A wise chemist told your teacher that it is always advisable to have baking soda (NaHCO3) on hand for safety when using strong acids. Why do you think this is so?

9. In this lab you used 6.0mol/L HCl, also known as muriatic acid. Suppose your teacher gave you 1.0mol/L HCl, in the same quantity, what would you expect to happen?

10. Your boss at the industrial chemical company has told you that you need to find the cheapest way to make hydrogen gas by reacting metals with hydrochloric acid. He can get Aluminum metal for $2.40/mol, Magnesium metal for $5.00/mol, and Sodium metal for $1.95/mol. Assuming that there are no safety considerations with using certain highly reactive metals (which there obviously are), which metal would be the cheapest to buy if he wants to make 1000L of hydrogen gas (at STP)? How much would this cost?

11. What sorts of companies produce/sell Hydrogen Gas? What are some of its uses? What safety precaution must be used?

12. The Hindenberg was a large airship (like a blimp) that was destroyed in a horrific accident in 1937. Describe the disaster in 3-5 sentences (Wikipedia has great information and a film showing the incident.) The blimp was full of hydrogen gas. Did this affect the disaster? How? What do current hot air balloons use to stay afloat? What do weather balloons use to stay afloat? Explain why hydrogen may have been a good choice for balloons in theory, but a bad practical choice.

**A** **full lab write-up,** with questions answered will be due. Your lab must include

**Purpose**

Why are we doing this lab? The purpose of this lab is to….

**Materials and Apparatus**

Please separate into materials and apparatus

**Procedure**

Refer properly to the textbook procedure but note necessary changes.

**Safety**

This I want you to rewrite, just to drill it in how important safety is. Don’t copy, but write in your own words.

**Observation table**

Your observation table must accompany your lab when handed in.

**Results**

Summarize your observations, but in proper sentences, also include answers to questions 1,2,4 in cohesive paragraph form. Calculations may be included here.

**Discussion**

Here is where you answer questions 5-12. Be sure to mention in your THREE sources of error and WHAT EFFECT the error would have had (e.g. this would have given us a higher molar volume than expected.)

**NEATNESS**: Your lab must be typed or NEATLY handwritten. Please PROOFREAD it for coherence (does the science make sense) and syntax (are you using proper sentence structure, is it easy to read, no grammatical/spelling errors). Marks will be deducted. Your calculations must be clean and easy to follow.

Your lab is due \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Observations**

*This observation chart MUST be attached as part of your lab report.*

|  |  |  |
| --- | --- | --- |
| **Observations** | Trial 1 | Trial 2 (time permitting) |
| Mass of magnesium ribbon (g) |  |  |
| Temperature of water (˚C) |  |  |
| Barometric pressure (kPa) |  |  |
| Volume of hydrogen gas collected (L – convert from mL) |  |  |
| Vapour pressure of water at this temperature (kPa) |  |  |

What are STP conditions? P = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ V = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ T = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Calculations: (you can use additional space if you need it)

|  |  |  |
| --- | --- | --- |
| **Results** | Trial 1 | Trial 2 (time permitting) |
| Number of moles of magnesium (mol) |  |  |
| Volume of collected dry hydrogen gas at STP (L) |  |  |
| Molar volume of hydrogen at STP (L/mol) |  |  |

**Calculating the Molar Volume of Hydrogen Gas – Pre-Lab Quiz**

What PPE (Personal Protective Equipment) must you wear for this lab?

What will happen if you get the acid on your skin? What will you do if this happens?

What is the purpose of the lab?

Here is the Ideal Gas Law. Draw a circle around variable(s) that will be measured during the lab. Draw a box around variable(s) that will be calculated. Underline any constants.

P V = n R T

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**LAB: The Production of Hydrogen Gas – TEACHER RESOURCE**

**When:** This lab should be used in the middle or near the end of the second half of the Gases Unit, once students have learned about molar volume, law of partial pressures, PV = nRT and have learned how to use it in calculations. Without this significant prior knowledge, students will not understand the lab.

**Why:** This lab helps students understand the quantitative relationships that define the ideal gas law, tying directly into one of the big ideas of the unit.

**Big Ideas:**

Chemicals react in predictable ways.

Relationships in chemical reactions can be described quantitatively.

It is important to use chemicals properly to minimize the risks to human health and the environment.

Properties of gases can be described qualitatively and quantitatively, and can be predicted.

**Overall Expectations:**

f2. Investigate gas laws that explain the behaviour of gases, and solve related problems;

f3. Demonstrate an understanding of the laws that explain the behaviour of gases.

**Specific Expectations:**

f2.1 use appropriate terminology related to gases and atmospheric chemistry, including, but not limited to: *standard temperature, standard pressure, molar volume,* and *ideal gas* [C]

f2.4 use stoichiometry to solve problems related to chemical reactions involving gases (e.g., problems involving moles, number of atoms, number of molecules, mass, and volume) [AI]

f2.5 determine, through inquiry, the molar volume or molar mass of a gas produced by a chemical reaction (e.g., the molar volume of hydrogen gas from the reaction of magnesium with hydrochloric acid) [PR, AI]

**Background:** The teacher must be comfortable handling caustic acids, and must know proper safety (goggles, gloves, wash any spills with copious amounts of water) and disposal (rinse down the sink with copious amounts of water). Also, the teacher must be familiar with the volumetric properties of gases, and use of the ideal gas law in calculations.

**Laboratory Set-up and Diagram**

The students will be set up in groups of 2-3 students on lab benches throughout the classroom as space permits. They can be on opposite sides of the lab bench if necessary as to allow sufficient bench space for all students. They will collect materials themselves from the unified collection located on a free bench or equipment cart, but the strong acid will be distributed by the teacher. On the diagram, the circles are students, arrows are exits, red is the equipment cart.

You will need the materials outlined on the lab protocol sheet, multiplied by the number of groups performing the lab. Most labs will have a 6.0 mol/L solution of HCl available. Higher molarities can be diluted as necessary. Lesser molarities can be considered, but less than ~3.0mol/L will lead to a less visual reaction.

**Materials/Apparatus for 8 groups:**

2-3 Scales (ideally to 3DP)

8 Large (~1L) beakers

8 100ml graduated cylinders

8 thermometers

8 two-hole stoppers

250ml 6M HCl

40-80 cm Magnesium Ribbon (if you want students to duplicate the experiment)

10 small pieces of steel wool

**Prelab Quiz**

Students will be asked to look over the lab ahead of time and will be told about a short (5 minute) prelab quiz (attached). This quiz is done to ensure student safety and that they understand the purpose of the lab. Safety is paramount when using strong acids.

Questions:

1. What PPE (Personal Protective Equipment) must you wear for this lab?
2. What will happen if you get the acid on your skin? What will you do if this happens?
3. What is the purpose of the lab?
4. Here is the Ideal Gas Law. Draw a circle around variable(s) that will be measured during the lab. Draw a box around variable(s) that will be calculated. Underline any constants.

Answers:

1. Gloves and goggles must be worn during the experiment.
2. If you spill acid, be sure to wash with lots of water and tell your teacher. If there is a big spill, your teacher will pour baking soda to neutralize the acid, then wash with lots of water.
3. The purpose of this lab is to find the volume of hydrogen gas collected so that we can determine the number of moles of hydrogen gas collected and through this calculate the molar volume of hydrogen gas at STP.
4. Volume, Pressure\*, and Temperature will be measured; Pressure\* and Moles will be calculated. R is the Universal Gas Constant (8.31J/molK) (Pressure = measured barometric pressure – Vapour pressure)

**Assessment and Evaluation of Student Acheivement**

The students will be assessed (AfL) through the pre-lab quiz to ensure that they understand why they are doing the lab and the safety precautions necessary. These are required before students attempt the lab, the rest of the information they can figure out as they go along, but it is imperative that this is understood prior to starting the lab.

The students will be assessed (AfL) for completion of the observation chart before they leave class on the day of the lab work. This is to ensure students know that there is an element of a deadline in class and they cannot ‘wait until they get home to do it’. This also prohibits students from copying their friends’ results.

The EVALUATION (AoL) of the lab is the lab report due 1-2 weeks after the lab. It requires that students understood the lab and were able to do the calculations. It also has a variety of questions regarding gases in general, and the lab itself. There are some simple questions, but others stretch students quite far. In a lab setting, it is good to involve more thinking/inquiry based questions as students are expected to spend some time working on these and discussing their results with their peers and figuring out optimal answers.

**Before Starting the Lab you MUST:**

* Ensure sufficient materials are available and that scales are in working order
* Ensure students are aware of safety considerations

**SAMPLE COMPLETED Observations**

*This observation chart MUST be attached as part of your lab report.*

|  |  |  |
| --- | --- | --- |
| **Observations** | Trial 1 | Trial 2 |
| Mass of magnesium ribbon (g) | 0.1215g |  |
| Temperature of water (˚C) | 22˚C |  |
| Barometric pressure(kPa) | 100.64kPa |  |
| Volume of hydrogen gas collected (L – convert from mL) | 55ml 🡪 0.055L |  |
| Vapour pressure of water at this temperature (kPa) | 2.64kPa |  |

What are STP conditions? P =101.325kPa T = 0˚C or 273K

Calculations: (you can use additional space if you need it)

Mg(s) + 2HCl(aq) → MgCl2(aq) + H2(g)

0.1215g / (24.31g/mol) = 0.005mol

(1 mol Mg : 1 mol H2 🡪 0.005 mol Hydrogen gas will theoretically be produced)

0.055L of Hydrogen gas collected

Temperature = 22˚C + 273 = 295K

Pressure Exerted by Hydrogen Gas = 100.64 kPa – 2.64 kPa = 98 kPa

PV = nRT n = PV/RT n = (98kPa\*0.055L)/(295K\*8.31 J/mol\*K) = 0.0022mol

(Percentage Yield = 0.0022mol/0.005mol = 44%)

\*molar volume = 0.055L/0.0022mol = 25L/mol)

Converting to STP conditions to find molar volume (L/mol):

PV = nRT

V= nRT/P = (0.0022mol \* 273K \* 8.31 J/mol\*K)/ 101.325kPa = 0.049L (for 0.0022 mol at STP)

0.049L/0.0022mol = X L / 1mol = **22.3L/mol at STP**

Actual Molar volume = 22.4L/mol at STP– well done!!

(Percent error – (22.3L/mol) / (22.4L/mol) = 0.995 🡪 0.005% error)

|  |  |  |
| --- | --- | --- |
| **Results** | Trial 1 | Trial 2 |
| Number of moles of magnesium (mol) | 24.31g/mol 🡪 0.01mol |  |
| Volume of dry hydrogen gas at STP (L) | 0.049L |  |
| Molar volume of hydrogen at STP (L/mol) | 22.3L/mol |  |

**Answers to Lab Questions:**

1. 25L/mol at experimental conditions
2. 22.3L/mol at STP
3. 0.005% error
4. The magnesium ribbon is covered in magnesium oxide (MgO) which will not react with acid. By rubbing it with steel wool, we expose the magnesium metal (Mg) so that it may react with the acid. Without this step, no reaction will occur.

6. Measurement issues, etc. Make sure that students properly indicate what effect the error had or would have had on their results (make it a greater/lesser value, etc.)

7. This is a single displacement reaction whereby Magnesium replaces Hydrogen. We know that a chemical reaction has occurred because a gas was produced (change in state).

8. Baking soda is basic (HCO3 ion) so we can use it to neutralize an acid spill, making it safer to clean up the area using a rag etc. Just like adding baking soda to vinegar (acetic ACID) creates a neutralization reaction.

9. It is possible that the reaction would not go to completion although this is based on the stoichiometric quantities. The assumption of the lab was that HCl is in excess, but if it isn’t, then we must calculate how much Mg was reacting.

10. The logic is that, because you are buying metal per mole and not per gram, you want to see what metal liberates the most hydrogen gas per mole. One mole of sodium liberates ½ mole of H2, a mole of magnesium liberates a mole of H2 but aluminum, owing to its valence of +3, liberates 1.5 moles of H2. When you look at the cost per mole, Aluminium comes out on top. At $2.40 per mole of aluminum, it works out to $1.60 per mole of H2 produced. 1000L /(22.4L/mol) = 44.64 mol x $1.60 = $71.43

12. There was a great explosion. Hydrogen gas is highly reactive and combustible so it sped up the reaction. Nowadays balloons are full of inert helium. Hot air balloons just use regular CO2 but it is heated so that it rises. Weather balloons are usually full of hydrogen, sometimes helium. (This is less of a concern for explosion because there is no ignition source, and the loss of a weather balloon won’t lead to a loss of life). As evidenced by the Hindenburg explosion, hydrogen gas is light and cheap, but it is highly reactive and will explode quite readily while Helium is inert and will not react violently if accidentally sparked. Imagine the pandemonium at kids’ parties if it did…